Proton stopping power ratio determination with basis material decomposition

Erik Pettersson[1,a], Magnus Gustafsson[2,3], Anna Bäck[2,3], Anne Thilander-Klang[1,2]

[1]Department of Radiation Physics, Institute of Clinical Sciences, Sahlgrenska Academy at the University of Gothenburg, Sweden.
[2]Department of Medical Physics and Biomedical Engineering, Sahlgrenska University Hospital, Gothenburg, Sweden.
[3]The Skandion Clinic, Uppsala, Sweden.
[a]Contact information: erik.a.pettersson@vgregion.se

PROTON STOPPING POWER RATIOS CAN BE CALCULATED FROM DECT MATERIAL DENSITY IMAGES

Background

The estimation of stopping power ratios (SPR) in human tissue from Computed Tomography (CT) Hounsfield units (HU) is a source for range uncertainties in hadron radiotherapy. Dual Energy CT (DECT) with projection based material decomposition, can in addition to HU, produce material density (MD) images. Here, the photon attenuation of an arbitrary material is represented as a combination of densities (in mg/cc) of two materials with differing effective atomic numbers (Z_{eff}) e.g. water and iodine.[1,2]

Purpose

The aim of this work is to present a direct parameterization of MDs, fitted to the tabulated photon attenuation of the human reference tissues, to their proton SPRs. This could reduce the range uncertainties associated with HU-to-SPR calibration curves.

Materials & Methods

The water and iodine MD combinations for 72 human reference tissues[3], were calculated using linear regressions of their attenuation coefficients to the mass attenuation coefficients of water and iodine[4], at nine photon energies (E) from 60 to 140 keV, in increments of 10 keV,

$$\mu^E = MD_{Water}\left(\frac{\mu}{\rho}\right)^E_{Water} + MD_{Iodine}\left(\frac{\mu}{\rho}\right)^E_{Iodine}$$

Additional MD combinations were calculated for tissue surrogates included in the 062M electron density phantom (CIRS Inc.), and other common phantom materials; polyethylene, polystyrene, polymethylmethacrylate (PMMA), polytetrafluoroethylene (PTFE) and graphite, which were used in reference 5.

The tissue SPRs for 226 MeV protons were calculated with the Bethe formula[6], using elemental mean excitation energies from ICRU37[7]. Two quadratic fits between the MDs and the SPRs were performed for soft tissues and bone, respectively. The MD-fitted SPRs were compared to the calculated SPRs.

Results

The soft tissue MD combinations contain nearly no iodine, while the bone tissues form a line in the water-iodine plane, separated from the soft tissues and the non-tissue equivalent materials i.e. PMMA, graphite and PTFE. (Figure 1)

The root-mean-square errors (RMSE) of all 72 fitted SPRs were within 0.09% of the calculated SPRs. The maximal and minimal SPR error ere 0.22% and -0.34% for “skeleton red marrow” and “eye lens”, respectively. (Figure 2)

Conclusion

Given accurate MD images from DECT with projection based material decomposition, the SPRs of human reference tissues can be determined to within a half percent.

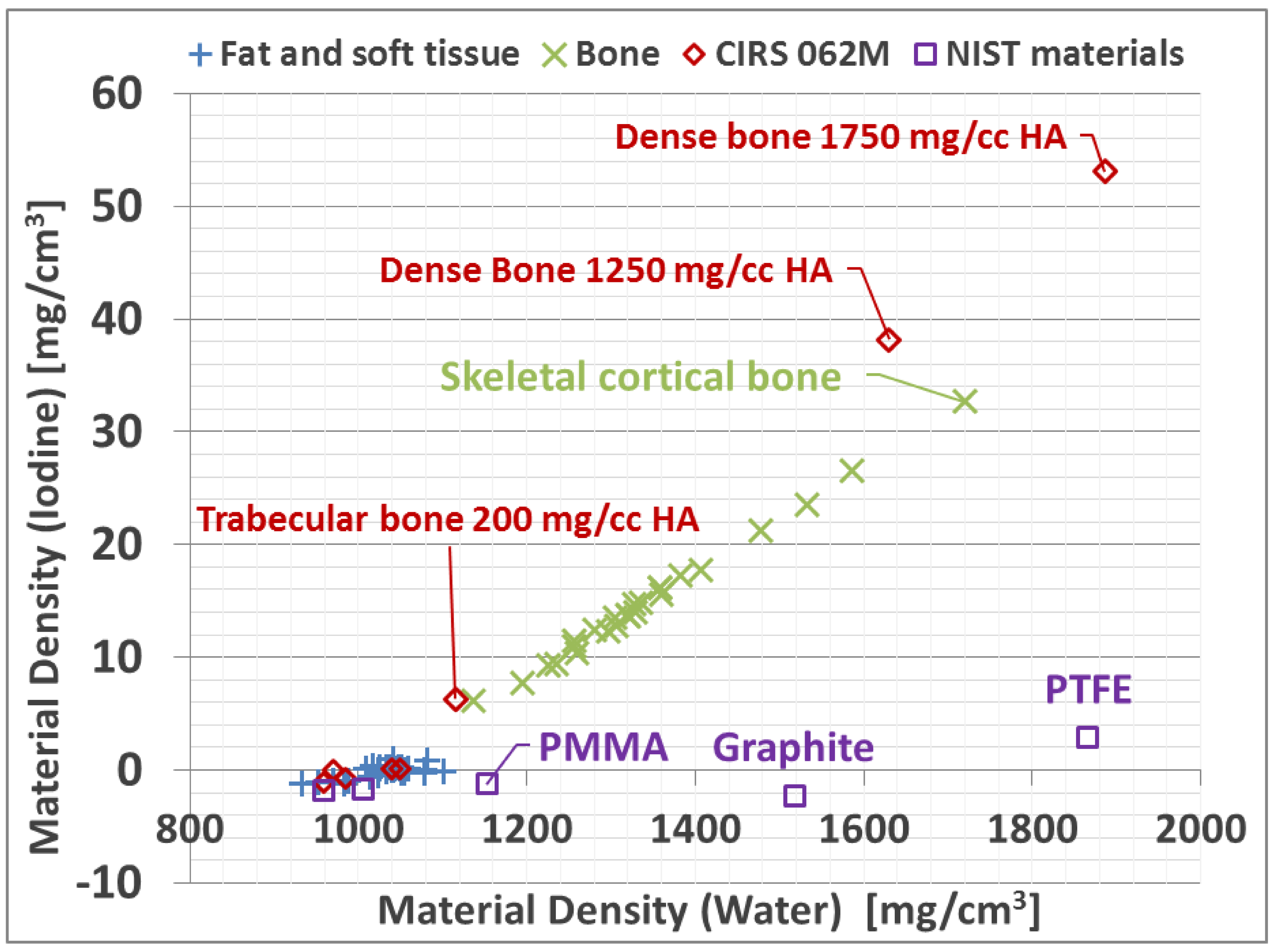

Figure 1. Two-dimensional plot of the photon attenuation expressed in water and iodine material densities (MD). The soft tissues separates from the bone tissues, which forms a line with increasing iodine MDs. In addition to the 72 human reference tissues, some common phantom materials and tissue surrogates are included for reference. NB: negative iodine MDs for materials with lower Z_{eff} than water, such as PMMA and graphite.

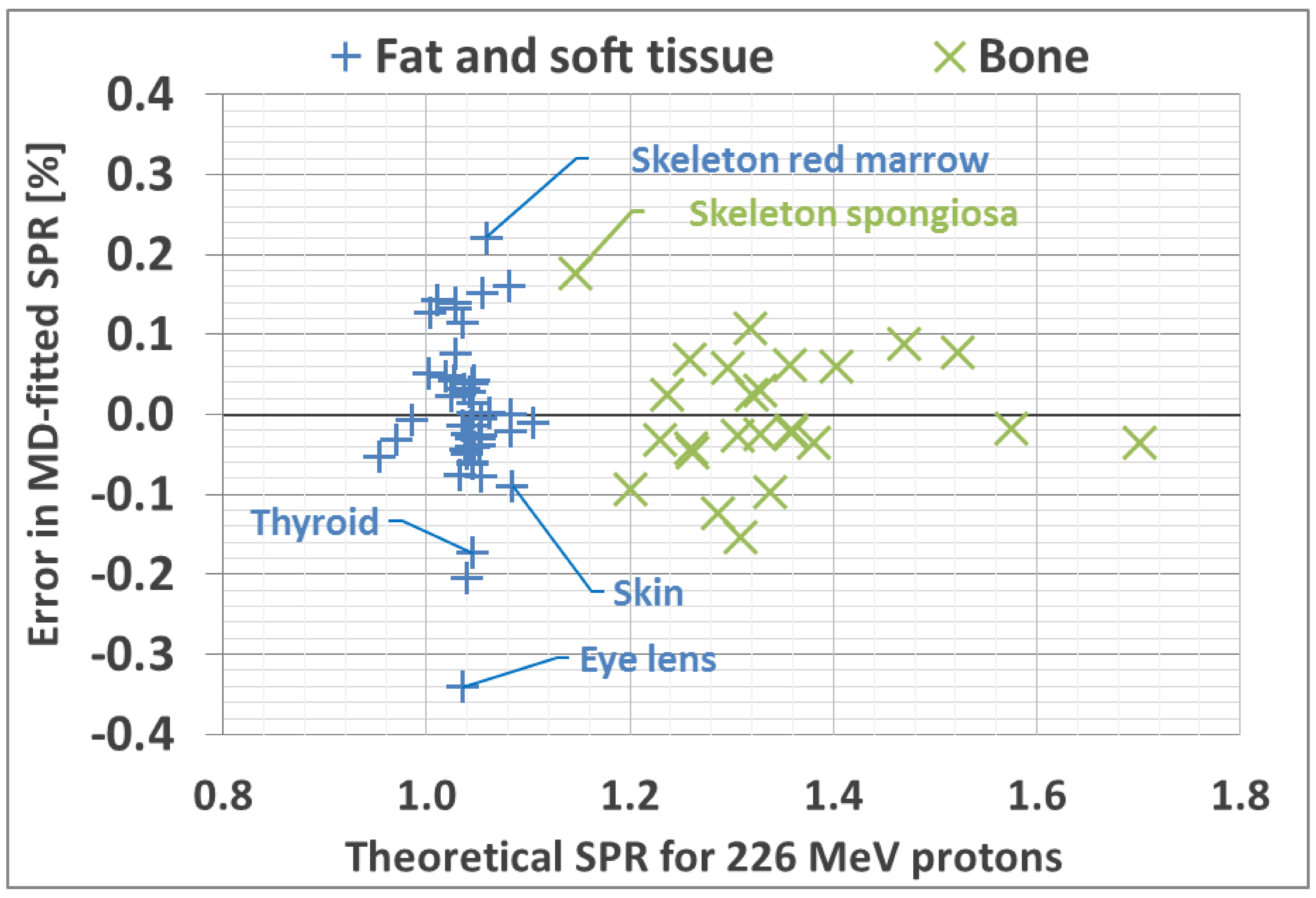

Figure 2. The percental errors of the MD-fitted SPRs compared to SPRs calculated with the Bethe formula.

References

[1] Alvarez RE, Macovski A. Energy-selective reconstructions in x-ray computerized tomography. Phys Med Biol 1976;21(5):733–744

[2] Lehmann LA, Alvarez RE, Macovski A., et al. . Generalized image combinations in dual KVP digital radiography. Med Phys 1981;8(5):659–667

[3] White DR, Woodard HQ. and Hammond SM. Br J Radiol 1987;60(717):907-13

[4] Berger, M.J., Hubbell, J.H., Seltzer, SM, Chang, J., Coursey, JS, Sukumar, R., Zucker, DS, and Olsen, K. (2010), *XCOM: Photon Cross Section Database* (version 1.5)

[5] Gustafsson M., Pettersson E, Thilander-Klang A. Validation of proton stopping power ratios for tissue surrogates in an electron density phantom, PTCOG56, poster #186.

[6] Schneider U, Pedroni E, Lomax A. The calibration of CT Hounsfield units for radiotherapy treatment planning. Phys Med Biol. 1996;41:111–124.

[7] ICRU37, Stopping Powers for Electrons and Positions (Report 37) (Bethesda, MD: International Commission on Radiation Units and Measurements)

REGION VÄSTRA GÖTALAND
SAHLGRENSKA UNIVERSITY HOSPITAL

Skandionkliniken

UNIVERSITY OF GOTHENBURG

Poster #188, Presented at the 56th Annual Conference of the Particle Therapy Co-Operative Group, Yokohama, Japan, May 2017.